United States Department of Agriculture
NATURAL RESOURCES CONSERVATION SERVICE
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ENGINEERING TECHNICAL NOTE

DAM SAFETY

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DAM WATCH

Emergency Seismic Evaluation – A qualified geologist and/or engineer will conduct a post-earthquake (emergency) inspection and analysis of the dam to identify conditions that may adversely affect safety and functionality. Evaluate the dam based on parameters listed in Tables 1-0, 2-0, and 3-0, and within the Emergency Action Plan (EAP). Notification for earthquake location, magnitude, and depth is available online through the U.S. Geological Survey Earthquake Hazards Program Notification Service (ENS) at https://earthquake.usgs.gov/ens/help.

Table 1-0: Modified from DNRC (2017). Correlation of Peak Ground Acceleration (PGA) to damage incurred from an earthquake

<table>
<tr><th>Intensity</th><th>Peak Ground Acceleration (g)</th><th>Dam Inspection Description</th><th>Damage Effects</th></tr>
<tr><td>I</td><td>< 0.0017</td><td rowspan="3">Dam owner or tender conducts cursory inspection. Damage is not expected.</td><td>Shaking not felt. Weak shaking. No damage. Felt by persons at rest and on upper floors; hanging objects swing. Vibration like passing of a light truck. May not be recognized as an earthquake.</td></tr>
<tr><td>II
III</td><td>0.0017- 0.014</td><td>Weak shaking. No damage. Felt by persons at rest and on upper floors; hanging objects swing. Vibration like passing of a light truck. May not be recognized as an earthquake.</td></tr>
<tr><td>IV</td><td>0.014- 0.039</td><td>Light shaking. No damage. Hanging objects swing. Vibration like passing of heavy trucks or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Car alarms activated. Windows, dishes, doors rattle. Glasses clink, crockery clashes. In the upper range of IV - wooden walls and frames creak.</td></tr>
<tr><td>V</td><td>0.039 – 0.092</td><td>Inspect the dam as soon as possible. Look for cracking, unusual seepage, or landslides. Photograph the dam site and compare with previous photographs. Measure piezometric levels in all instrumentation. Damage not expected, but possible.</td><td>Moderate shaking. Very light damage. Felt outdoors. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close/open. Shutters and pictures move; pendulum clocks stop, start, change rate.</td></tr>
<tr><td>VI</td><td>0.092 – 0.180</td><td>Conduct immediate inspection and contact the engineer to get on site as soon as possible. Significant damage is possible. Not all damage may be visible Note: buildings and cell phone towers may be impacted.</td><td>Strong shaking. Light damage. Felt by all: many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc. off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small church and school bells ring. Trees, bushes shaken.</td></tr>
</table>

Table 1-0: Modified from DNRC (2017). Correlation of Peak Ground Acceleration (PGA) to damage incurred from an earthquake

Intensity	Peak Ground Acceleration (g)	Dam Inspection Description	Damage Effects
VII	0.18 – 0.340	Dam owners should be concerned about damage that could lead to failure. Owner and engineer should get to the dam as soon as possible. Conduct an immediate inspection. Significant damage is possible. Not all damage may be visible.	Very strong shaking. Moderate damage. Difficult to stand. Noticed by car drivers. Hanging objects quiver. Furniture broken. Damage to masonry D including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stone tiles, cornices, unbraced parapets, and architectural ornaments. Some cracks in masonry C. Waves on ponds; water turned turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete culverts damaged.
VIII	0.34 - 0.650		Severe shaking. Moderate to heavy damage. Steering of motor cars affected. Damage to masonry C: partial collapse. Some damage to masonry B, none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and steep slopes.
IX	0.65 - 1.240		Violent shaking. Heavy damage. General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Structures shifted off foundations if not bolted down. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks on ground. Sand boils and sand craters.
X	>1.240	Damage could lead to dam failure. Owner and engineer must get to the dam as soon as possible.	Extreme shaking. Very heavy damage. Most masonry and frame structures destroyed, with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand shifted horizontally on beaches and flat land. Rails bent slightly.
XI XII	* *		Extreme shaking. Very heavy damage Rails bent greatly. Underground pipelines completely out of service. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

**Note: At the highest intensity levels, damage potential is determined increasingly by the effects of ground failure. Most types of ground are unable to sustain prolonged accelerations much greater than 0.50g.*

Use this guidance for post-earthquake emergency inspection and analysis of the dam to identify conditions that may adversely affect safety and functionality (Table 2-0). The qualified geologist and engineer must use the hazard classification system contained in the Title 210-National Engineering Manual (NEM), Part 631 Geology-National Engineering Handbook (NEH), and below visual adverse conditions to assess the dam as soon after the earthquake occurrence as practical.

Table 2-0: Dam Evaluation Post-earthquake adverse conditions

Adverse Condition	Description
Embankment and Reservoir	
Displacement	Evaluate the dam embankment crests and roads, utility lines, or other lineaments parallel to, or concentric to, the embankment for any abnormalities, including depressions, sags, scarps, and cracking.
Settlement	Settlement is a potential early warning sign for piping failures and mass movement. Settlement is evidenced by a lowered crest elevation, cracking, or depressions that result from collapse of embankment or foundations with low density fine sand or silt. Differential settlement can lead to tensile strains and eventual development of transverse cracking. Longitudinal cracking can develop, but are not necessarily a threat to the dam unless cracking is associated with transverse cracking.
Subsidence Depression	Subsidence, depressions, or sags could be indicative of foundation settlement, solutioning, or piping. Probe the depression, record dimensions, and use the Unified Soil Classification System (SCS) to classify soils.
Cracking	Cracking in and on the dam can develop from earthquakes, and *may* lead to embankment failure if water flows through the cracks, and creates erosion and piping of material. For all cracking, record orientation, openness, spacing, and depth.
Sinkhole	Sinkholes form from erosion and/or piping of poorly compacted soil or soft erodible rock. Sinkhole indicators *may* include depressions; holes that typically have an hour glass shape, narrow at the top and wide at the bottom; seepage; and seepage with discoloration. Probe the sinkhole, record dimensions, sample and classify the soil, calculate flow rates (if present and possible), inspect for sand boils, accurately map sinkhole.
Bulges	Examine the upstream and downstream embankment faces for bulges or any variance from a smooth, uniform plane. Bulges are indicative of both surficial and subsurface slope movement. Survey any suspected changes.
Seepage	Uncontrolled seepage can lead to embankment and foundation erosion and piping, voids, material collapse, and structure failure. Examine for wet spots, sand boils, depressions, sinkholes, springs, evaporates, and abnormal vegetation growth. Inspect for suspended solids, discoloration, and stake, survey, and measure seepage.
Instrument Monitoring	Measure inclinometers, piezometers, and seepage measuring devices (weirs). Instrumentation can detect vertical (horizontal) and horizontal (shear) movement and fluctuations in water-levels.
Surface Erosion	Examine all embankment surfaces for erosion. Causes of erosion include inadequate slope protection, excessive rainfall, and concentrated surface runoff. Identify the presence of highly erodible silts or dispersive clays.

Table 2-0: Dam Evaluation Post-earthquake adverse conditions

Adverse Conditions	Description
Animal burrows and Vegetation	Remove vegetation that obstructs a clear view of the embankment. Examine and identify vegetation. Vegetation requiring large amounts of moisture are suspect and could indicate wet spots or seepage paths within or below the embankment. A color difference within an area of same type of vegetation is a good indication of wet spots. Rodent activity on the dam face or toe could reduce the seepage path length which could lead to erosion and piping. Determine location and extent of tunneling. Remove rodents and backfill existing holes.
Examine Reservoir	Examine the reservoir rim for subsidence, sinkholes, trenches, and settlement of nearby highways and structures. Identify vortexes, movement in the water surface, and turbidity.
Landslides	Sloughing or mass movement can have adverse effects on the dam, appurtenances, reservoir, or access routes. The examiner must be knowledgeable about landslide causes, mechanisms, characteristics, symptoms, and treatment. Identify landslides by looking for escarpments, tilted trees, areas of dead or dying vegetation, tension cracks, hillside distortions, misalignment of linear features, encroachment of shoreline vegetation into the reservoir, and springs. Estimate the slide dimensions (length, width, depth), classify the soils within the slide area, and determine the source for movement.
Timing	If the earthquake occurs under low pool conditions, the initial inspection should still take place as soon as possible after the event. However, careful monitoring during the first filling after the event is strongly recommended to identify any issues that were not possible to detect during the initial inspection.
Unusual Conditions	Identify any unusual or suspect conditions that may not fall into any of the aforementioned adverse conditions.
Structures	
Settlement	Uniform settlement of structures is a potential early warning sign of foundation problems that are not seen in earthfill or natural ground surfaces due to arching and the time required for some localized/ isolated foundation failures to reach the surface. Uniform settlement is evidenced by a lowered structure elevation in relation to the pool level or local datum. Settlement of a riser without corresponding conduit settlement can cause cracking and leakage allowing for embankment erosion and uncontrolled discharge. Differential settlement can also be a warning sign of foundation problems not otherwise obvious at the ground surface. Evidence can be tilting, rotation, or new cracks in the structure. Earthquake related differential settlement could also cause gates and gate operators to bind that operated freely prior to the event.
Distress	Structures can show signs of distress caused by soil movement and in some cases, movement within the structure is more obvious and more easily measured than movement of the soil surrounding it. Structures should be checked for new cracks, displacement from original position or other components, and misalignment. Excess lateral loading during earthquake events or slope movements can cause loss of foundation contact pressure on one side of a structure thereby opening a path for internal erosion leading to embankment failure.

Table 2-0: Dam Evaluation Post-earthquake adverse conditions

Adverse Conditions	Description
Seepage	Changes in drain flow conditions can be an indicator of internal problems that are impossible to see: 1. Check for changes in flow rate from pre-earthquake conditions, and 2. Note any transport of solids, suspended or otherwise, as their movement indicates removal of material. Note type of material being transported, i.e. sands and small gravel could indicate failure of a drain pipe or joint allowing filter or drain aggregate to escape. Many times there is not sufficient velocity to transport the larger size particles, so only the smaller fraction is delivered to the outlet. Conditions associated with outlet conduits and structures warrant careful observation. 1. New and/or turbid seepage along the conduit exterior indicates changes have occurred that endanger the safety of the embankment. 2. Check for discharge from conduits that are closed and compare to pre-earthquake conditions. Abnormal discharge could indicate conduit cracking or joint damage allowing direct flow and possible internal embankment erosion.
Unusual Conditions	Identify any unusual or suspect conditions that may not fall into any of the aforementioned adverse conditions.

Table 3-0: Seismicity of Montana High Hazard Dams in relation the geology. **Piezo** = Piezometer

Dam	Fed. I.D.	Legal	County	Lat/Long	Hazard Class	Seismic Zone	Geology	Piezo
East Fork Dam	MT-1567	Sec. 11 and 14, T14N R 19E	Fergus	46.9830, -109.2806	1	2	Embankment Foundation: Fat clay, sandy clay, clayey sands; gravel, sand, clayey gravel, and silty gravel seams throughout. Overlies shale to clayey shale bedrock. Left Abutment: Siltstone and shale. Right Abutment: Shale and limestone. Embankment: Zoned embankment (1-4) - composition not described; likely clay. Chimney drain, stability berm, and emergency spillway present.	Yes
Pike Creek Dam	MT-1568	Sec. 29, T15N R19E	Fergus	47.0365, -109.3513	1	2	Embankment: Zone1: Impervious clay; Zone 2: Drain fill; Zone 3: Shale excavated from emergency spillway; Zone 4: Riprap. Embankment Foundation: Kootenai Formation shale and resistant sandstone. Valley Foundation: 30 feet of saturated alluvial sands and sandy clays Right Abutment: Colluvial soils over sandstone and shale. Left Abutment: 40 feet of alluvial clays and clayey sands overlying bedrock. Chimney drain, emergency spillway, and stability berm present.	No

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Dam	Fed. I.D.	Legal	County	Lat/Long	Hazard Class	Seismic Zone	Geology	Piezo
Big Casino Creek Dam	MT-1569	Sec. 27, T14N R18E	Fergus	47.0363615 -109.4282379	1	1	<u>Embankment Foundation:</u> Terrace gravels; highly fractured Kootenai Formation sandstone and siltstone. Low to high plasticity clays with silty sand, or gravelly clays. <u>Embankment:</u> Zoned embankment (1-3). Geology not identified for zones. Consists of medium to high plasticity clays (determined from borrow area). <u>Valley Foundation</u>: 12 to 24 feet of alluvium overlying bedrock. Alluvium removed below the dam. No chimney drains; toe drains, stability berm, and emergency spillway present.	No
Hanson Creek Dam	MT-1570	Sec. 5, T14N R19E	Fergus	46.9989 -109.3361	1	2	<u>Embankment: Zone 1</u>: Silty sandy clays and clayey sands. <u>Zone 2</u>: Pervious gravel drain fill. <u>Zone 3</u>: Sandy silty gravels, gravelly sands, shales, sandstone, and limestone. <u>Zone 4:</u> Sandy silty gravels, gravelly sands, and sandstone and limestone. <u>Embankment Foundation:</u> Medium to high plasticity clays, fat clays, poorly graded gravels, silty sands, and silts. <u>Valley Foundation:</u> Gray, drab, brown and red non-marine shale, mudstone, siltstone, and sandstone of the Morrison Formation. <u>Left Abutment Foundation:</u> Shale and mudstone sequence. <u>Right Abutment</u>: More resistance siltstone. Chimney drain and emergency spillway present.	No

Table 3-0: Seismicity of Montana High Hazard Dams in relation the geology. **Piezo** = Piezometer

Dam	Fed. I.D.	Legal	County	Lat/Long	Hazard Class	Seismic Zone	Geology	Piezo
Christianson Coulee Dam	MT-01471	Sec. 19, T23N R60E	Richland	47.7384, -104.0601	1	0	Left Abutment: Clay, Silt, and Fort Union Formation with coal seams. Right Abutment: Fort Union Formation rock. Dam Foundation: Wet Clay approximately 10-feet-thick overlying bedrock. Embankment: Predominantly silt with small silty sand and clay beds (< 3-ft-thick). No chimney drains. There is a stability berm. Homogenous dam.	No
Sturgis Coulee Dam	MT-1398	Sec. 30, T23N R60E	Richland	47.7275, -104.0743	1	0	Left Abutment: Clay to at least 11.0 feet. Right Abutment: Cretaceous bedrock. Embankment Foundation: > 10 ft of silt, clay, and silt sand (in that order) on top of Fort Union Formation. Embankment: Predominantly silt with some silty sand. No chimney drain. There is a stability berm. Homogenous dam.	No

Table 3-0: Seismicity of Montana High Hazard Dams in relation the geology. **Piezo** = Piezometer

Dam	Fed. I.D.	Legal	County	Lat/Long	Hazard Class	Seismic Zone	Geology	Piezo
Burnt Fork Dam	MT-1168	Sec. 3, T6N R18W	Ravalli	46.304, -113.8378	2	2	Foundation: Glacial till deposits up to 20-feet-thick overlying quartzite and siliceous shale bedrock. Right and Left Abutments: Glacial sediments. Embankment: Homogenous; 40-50% sand and silt; 55-60% clays. Emergency spillway present; no drains present.	No
Lower Willow Creek Dam	MT-1155	Section 2, T9N, R14W,	Granite	46.5591 -113.3143	1	3	Embankment: Zoned (1-3); Zone 1 Impervious clay; Zone 2, Chimney Drain; Zone 3, Earth and gravel fill. Formation: Tertiary aged silty and clay with tan to pink volcanic ash "lake bed" sediments. Spokane Formation sandstone and shale. Cambrian rocks consists of Flathead quartzite, Silver Hill Formation (calcareous shale), Hasmark Formation (magnesian limestone with calcareous shale), and Red Lion Formation (limestone). Chimney drain, stability berm, and emergency spillway present.	Yes
Jaw Bone Dams 1 and 2 and Dikes (2)	MT-70 MT-71	Sec. 21 and 22, T8N R15E	Wheatland	46.4411, -109.8332 46.4450, -109.8395	1	2	Dam1 Foundation: Alluvium (1-4 ft) overlying shales and sandstones. Blanket and cut off trench. Dike 1 Foundation: Alluvium (<10 ft) overlying shale and weathered sandstone. No cutoff or blanket toe drain. Dike 2 Foundation: Shales and sandstones. No drains present.	No

Table 3-0: Seismicity of Montana High Hazard Dams in relation the geology. **Piezo** = Piezometer

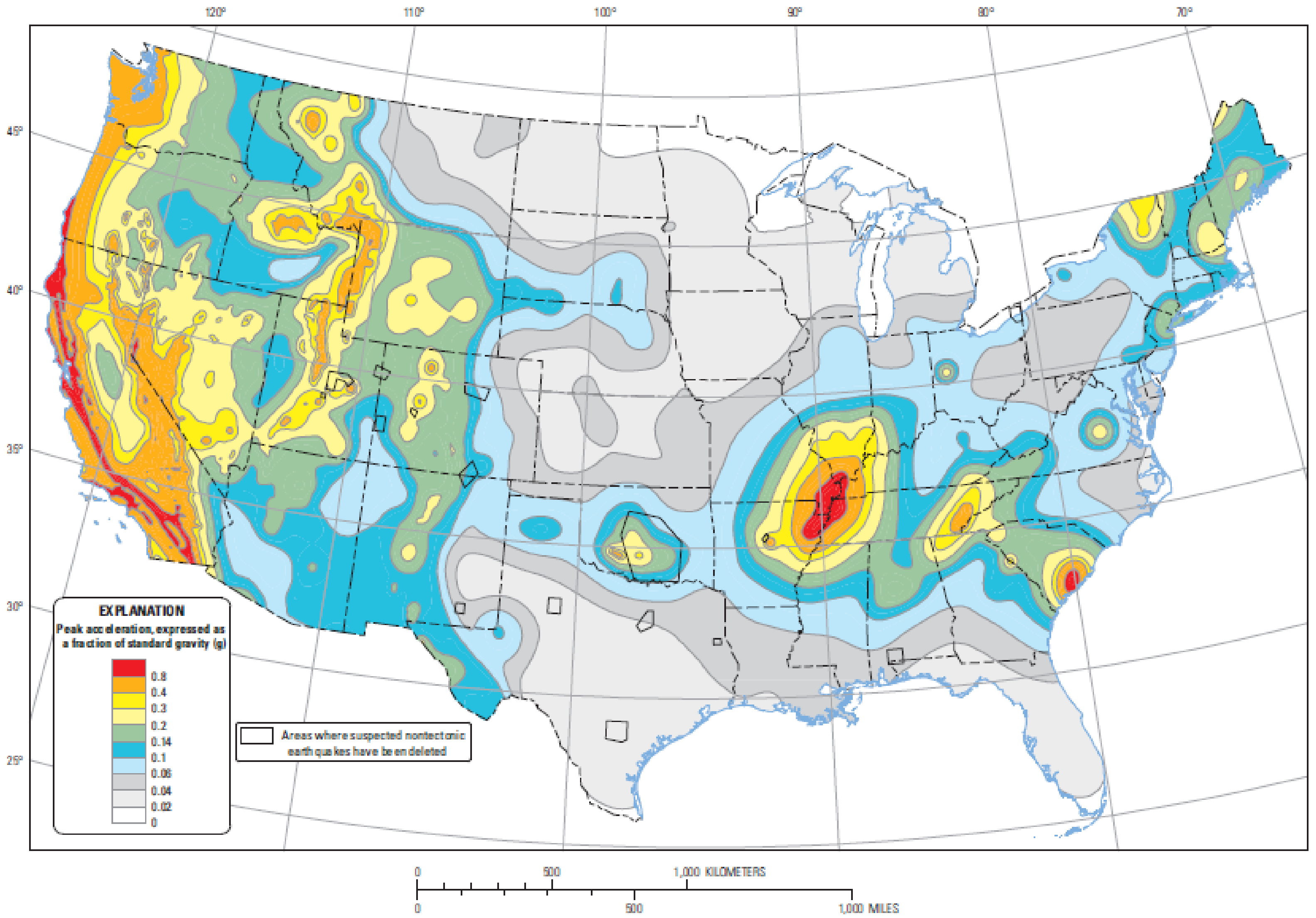
Dam	Fed. I.D.	Legal	County	Lat/Long	Hazard Class	Seismic Zone	Geology	Piezo
Cowpath Dam	MT-3203	Sec 15 and 22, T32N R2W	Toole	48.5198, -111.8487	1	2	Embankment Foundation: Glacial till and weathered, reworked shale. Embankment: Glacial till (silty to sandy clay devoid of large gravels, cobbles, and boulders). Abutment Foundation: Not identified. No Chimney drain; toe drain and stability berm present.	No
Sullivan Dam	MT-2004	Sec. 15 and 22, T32N R2W	Toole	48.5246, -1118530	1	2	Embankment Foundation: Glacial till (clay, silt, silty sand, poorly graded sand, gravelly clays, and elastic silt) and weathered re-worked shale. Embankment: Homogenous. Glacial till (silty to sandy clay devoid of large gravels, cobbles and boulders). Abutment Foundation: Not identified. No Chimney drain; toe drain and stability berm present.	No
Beaver Creek Dam	MT-510	Sec 25, T31N R15E	Hill	48.4164, -109.7326	1	1 and 2	Embankment Foundation: Alluvium (0-15-ft-thck) overlies glacial till (medium to high plasticity clays) and felsic volcanic agglomerate. Embankment: Homogenous. Silty to sandy clays, same as glacial till. Chimney Drain and stability berm present.	Yes

Table 3-0: Seismicity of Montana High Hazard Dams in relation the geology. **Piezo** = Piezometer

Dam	Fed. I.D.	Legal	County	Lat/Long	Hazard Class	Seismic Zone	Geology	Piezo
Cedar Creek Dam	MT-1455	Sec. 27 and 34, T31N R20W	Flathead	48.4137, -114.1449	1	2	Foundation: Glacial deposits, ~80-feet-thick (poorly graded gravel, clay, silty gravel, poorly graded sand, silty sand) that overly glaciolacustrine clays. Abutment's Foundation: Glacial recessional moraine, consisting of sands, gravels, and boulders. Embankment: Zone 1: Impervious clay (CL); Zone 2: Gravel transition zone, well graded sub-rounded gravels. Zone 3: Riprap. No chimney drain or stability berm; toe drain present.	No
Upper Baker Lake Dam	MT-1564	Sec. 18, T7N R60E	Fallon	46.3554, -104.2602	1	1	Foundation: Clayey alluvium underlain by Pierre Shale. Embankment: Zoned (1 and 2). No chimney drain. Right and Left Abutment Emergency Spillway present.	No

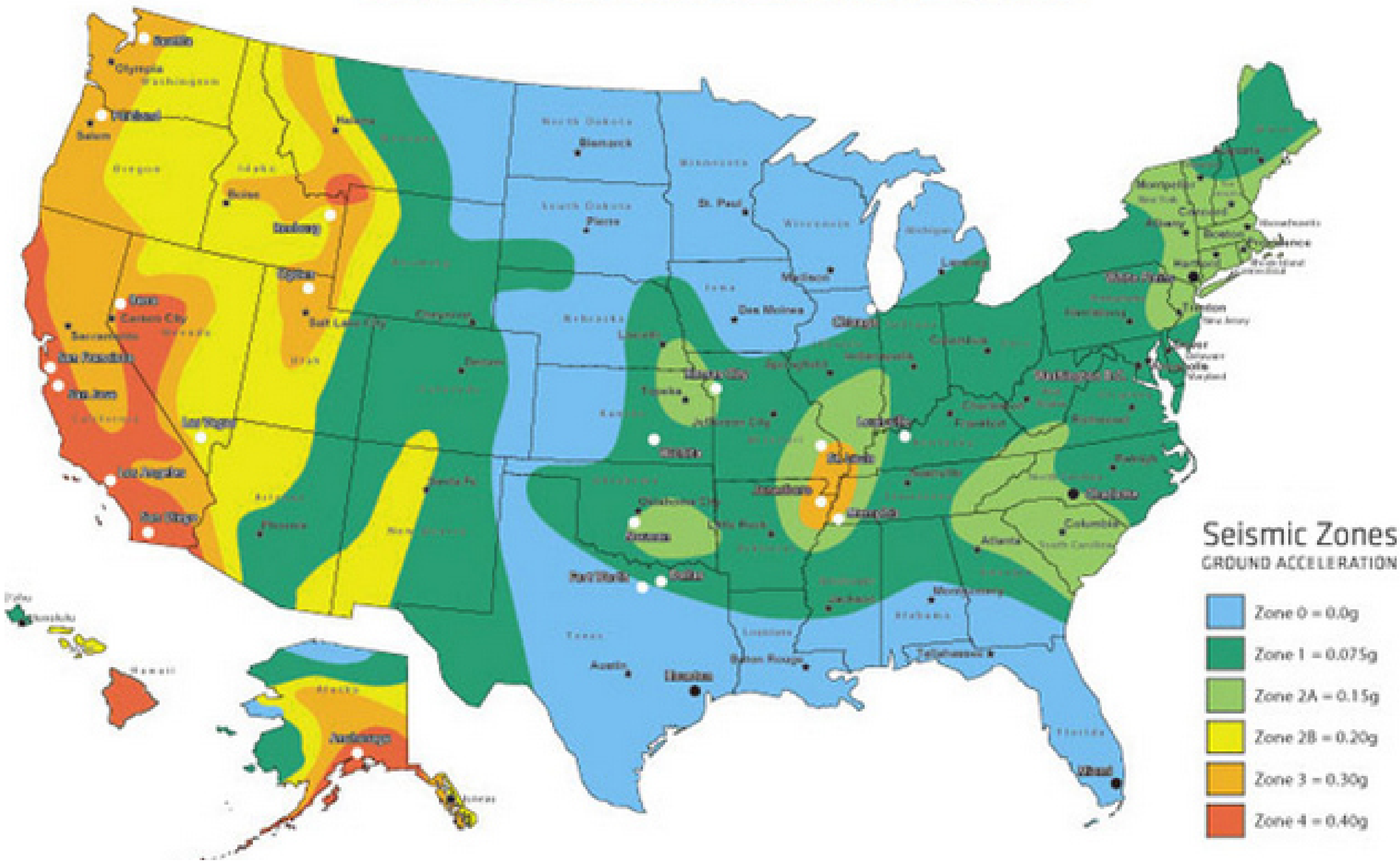
Table 3-0: Seismicity of Montana High Hazard Dams in relation the geology. **Piezo** = Piezometer

Dam Name	Fed. I.D.	Legal	County	Lat/Long	Hazard Category	Seismic	Geology	Piezo
Box Elder Creek Dam	MT-934	Sec. 17, T35N R55E	Sheridan	48.7867, -104.5543	1	1	<u>Right Abutment Foundation</u>: Shale encountered at "shallow depth" below right abutment. Glacial till within abutment. <u>Left Abutment Foundation</u>: Sands and gravels found above shale near the left abutment. Sand and gravels are clean and up to 6-feet-thick. Glacial till within abutment. <u>Dam Foundation</u>: Alluvial fill consisting of silty, gravelly sand to approx. 50 feet. Underlain by glacial till, consisting of silt, sand, gravel, and boulders. Blue clay or weathered shale. <u>Embankment</u>: Glacial till. No chimney drain; stability berm and toe drain present.	No



Two-percent probability of exceedance in 50 years map of peak ground acceleration

United States Seismic Zones



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